

# XRTD: AN X-WINDOWS BASED, REAL-TIME RADIOMETRIC DISPLAY AND ANALYSIS SYSTEM

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## ABSTRACT

XRTD is a graphical user interface (GUI) based tool for monitoring real time radiometric spacecraft data. The tool is designed to allow the navigation analyst to both view and analyze the characteristics of Doppler and ranging data. This capability is critical, if ground personnel wish to verify the correct performance of ongoing maneuvers. The raw tracking data is transferred from Deep Space Network (DSN) computers to a local workstation, where the predicted value for the observable is subtracted from the actual observed value to create a residual. The tool then allows the navigation analyst to rescale and replot the data using simple GUI techniques. The navigator may then perform a number of data analysis and modeling techniques on the resulting residuals to allow for the real time characterization of spacecraft events. These techniques include the modeling of maneuvers, the compression and differencing of data, and Fast Fourier transforms of the data. This tool has shortened the amount of time required for initial characterization of spacecraft maneuvers from several hours to a few minutes.

**Key Words:** Aerospace, space, navigation, operations, GUI, XWindows

## 1. INTRODUCTION

The display and analysis of radiometric tracking data is, and has always been, fundamental to the navigation of interplanetary missions. Traditionally, these two functions have been somewhat bifurcated. Display usually meant generation of plots of data residuals (the difference between the value of an observation and the expected value of that observation from the numerical models) to look for general trends in data priori to its analysis or to assure that no

gross abnormalities remained in the data after analysis. Analysis traditionally consisted of number-crunching on large main-frame computers and the output was ordinarily tabular text.

The workstation revolution, providing powerful compact computers equipped with high resolution graphics displays and high quality output devices, as well as the possibility of mouse driven operation of software, resulted in a new type of navigation tool, the graphical-analysis program. The computation speed of the workstations coupled with the growing prevalence of high speed data networks (such as those based on TCP/IP) further allows the graphical analysis tools to be connected to the real-time flow of data. This creates capabilities not previously possible and enhances previously existing ones to previously unthought-of levels.

### 1.1 Background

The basic radiometric observations received from spacecraft are Doppler and range data. Doppler data is simply the difference between the frequency of the radio signal received by the tracking station as compared to the frequency of the signal that was originally broadcast. This signal may have been broadcast by the receiving station and relayed by the spacecraft (2 way Doppler), transmitted by a second ground station and relayed by the spacecraft (3 way Doppler), or originated by the transmitter on the spacecraft itself (1 way Doppler). Range data can simply be thought of as the time delay between when a specified signal is broadcast from the originating ground station to when it is received back on the Earth. Like Doppler data, range data can be either 2 way or 3 way depending on if the transmitting station is the receiving station. (1 way range data is not used in interplanetary navigation.) Conversion of the received radiometric signal to data residuals

involves both the removal from the received signal of calibration values which depend on the ground station configuration and conversion of the predicted position and velocity of the spacecraft to an expected value of either Doppler shift or signal delay. In the case of Doppler data the received frequency of the data is subtracted from the transmitted frequency at a time which is twice the light time to the spacecraft before the receipt time. The primary problems with range data are applying the calibration for the delay induced by the receiving and transmitting stations and calculation of the ambiguity of the range delay. The ambiguity is such that for an observed signal delay,  $d$ , the actual delay is

$$nk + d \quad [\text{Eq. A}]$$

where  $k$  is a constant which depends on the ground station configuration and  $n$ , the range ambiguity, is a positive integer. Fortunately,  $k$  is generally large enough and *a priori* knowledge of the Earth relative range good enough that calculation of  $n$  is possible.

The primary purpose of a real-time graphical analysis tool is to perform real-time data validation and real-time spacecraft analysis. The first allows navigators to assess the effect of spacecraft and ground station configuration changes on data quality or availability. For example, this allows the determination of transmitter power to allow successful acquisition of data without requiring many passes of data to slowly determine the minimum value. The second purpose allows analysts to examine spacecraft activities as soon as the effects are visible at the Earth. These activities can include maneuvers or anything which changes the physical state of the spacecraft.

## 1.2 Precursor methods

In the past other methods have been used for near real-time data validation and analysis of spacecraft activities. The most common of these are referred to as real-time pseudo-residual displays and near real-time residual plots.

The first of these is a display capability provided by the DSN. The DSN calculates the expected received frequency received at a ground station based on a predicted spacecraft state file and based on predicted values of the ground station

configuration. When the actual signal is received, this predicted received frequency is differenced from the actual received frequency to calculate a pseudo-residual. These pseudo-residuals are then sent to low resolution displays which are in the possession of the flight team analysts. The drawbacks of the system are that a long lead time is required for the generation of these predicted values. If the ground station configuration at the receiver or transmitter is changed between the time the predicted values are generated and the actual observation, then the pseudo-residuals may be grossly wrong. Additionally, the fairly low resolution of the displays makes the determination of precise values difficult. No way to import the information from the displays into any analysis package exists. Finally, pseudo residual displays are not available for range data.

The second method for performing data validation tasks and for analyzing spacecraft activities was use of a near real-time residual plot. In general, this system was only used for analysis of maneuvers. This system involved using a high resolution plot of data generated by the analysts who first receive the data. The normal function of this group is to examine the data for gross calibration errors and if possible repair them and to remove obviously bad data points. However, this group can produce higher resolution plots of true residuals. Using these plots the navigation analysts then attempted to, by eye, place curves (usually linear) through the data and from the curves calculate the value of a maneuver. This system had the obvious drawback of being only as precise as the ability of the individual analyst to place the line through the data. For a typical spacecraft maneuver this could only be on the order of 5%. Additionally, the generation of these high resolution plots generally took in excess of one hour.

The desire to combine the true residuals and the high resolution capability of the near real-time residual plots and the real-time nature of the pseudo-residuals with a tool which removed the human element in placing curves through the data led directly to the design of the XRTD system.

## 2. SYSTEM DEVELOPMENT

Several basic capabilities are required of any real-time navigation graphical analysis tool. Access to real-time data must be had, calculation of residuals from the basic tracking parameters must be achieved, and then the display an analysis of the residuals must be accomplished.

The difficulty of combining all three of these functions into a single program as well as a desire to as much as possible utilize already existing software tools resulted in a decision to split the three function into four pieces of software. The first two transfer real-time data to the analyst's workstation, the third generates the residuals, and fourth is the actual graphical analysis software. The advantage of this system is that all three functions can be developed and tested separately. Additionally, much prior work has been done in the generation of residuals that could be drawn upon.

### 2.1 Data flow structure development

For simplicity, the decision was made to not attempt to develop interfaces directly with the data flowing from the DSN stations, but rather, to tap into the flow of data after it had already been collected at one point. The advantage of this is obvious, however the primary disadvantage is that the computer where all the data is brought together did not at the time of the software development have direct access to any analysts machine. However, a secure interface machine did exist and the decision was made to utilize it to provide the data flow. Two processes facilitate the data flow. The first resides on the intermediary microVAX. It tests for the existence of new data on the primary data collection machine and if it exists, then transfers the data from the data collection machine to the navigation workstation. The second simply receives the data on the navigation workstations and updates the data file on this machine. As this file is updated, the third piece of software generates the residuals and corresponding timetags. These are then output as an updated ASCII text file which can be read by the graphical analysis software. A block diagram of this data flow can be seen in Figure 1. The two tools which transfer the data are named

*sprnet* and *sprd*. The residual generation tool is called *rtd* and the graphical analysis tool is *Xrtd*

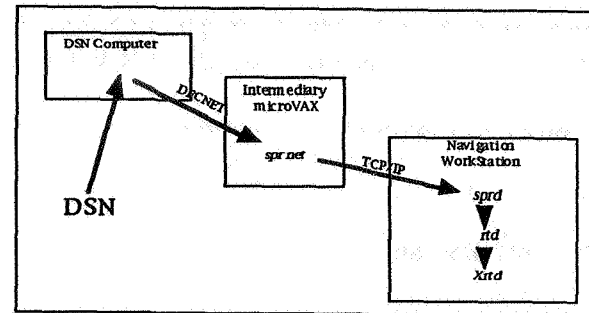


Figure 1: Block Diagram of Data Flow

### 2.2 Analysis tool development

One of the major advantages of the system described in the previous section is that the development of the graphical display and analysis tool is decoupled from the data acquisition and calculation portion of the problem. Analysis of commercially available graphical analysis tools indicated that none met the unique needs of the real-time display problem. Consequently, the decision was made to develop an independent tool to perform this analysis. The tool was designed using the X-Window System (commonly called Xwindows) developed by the Massachusetts Institute of Technology (Ref 1.). This windowing system provides the advantages of being portable and non-hardware vendor specific. Additionally, it provides basic capabilities from which any graphical user interface (GUI) can be built. The mode in which *Xrtd* was developed and designed to be used in integrates an Xwindows based system with the OSF/Motif GUI developed by the Open Software Foundation (Ref. 2). These two choices maximize the software portability.

The design philosophy was to provide a series of basic capabilities for displaying data such as rescaling the data plots and changing the time span of the plots which would not necessarily require use of keyboard inputs. Consequently, the plot span can be controlled via slider bars and the plot can be rescaled simply by selecting a rectangular portion of a plot with the mouse. The plot will be rescaled to display that portion on the whole plot.

Additionally, analysis of the data is undertaken by creating new plots which are described as "children" of the plot from which they originated. New "children" are spawned simply by accessing a command on a pull down menu. The "child" plots may in turn be treated as a "parent" and spawn more "children". Consequently, complicated adjustments and analysis may be performed on data by coupling simple processes together in series. A single "parent" plot can have multiple "children", thus allowing the on screen comparison of differing data analysis strategies. A graphical display of all plots is maintained to prevent the user from becoming confused and the user can access any plot by selecting its icon from the plot-tree. A number of "child" plots as well as the plot summary chart and the pull down menu which generates "child" plots can be seen in Figure 2.

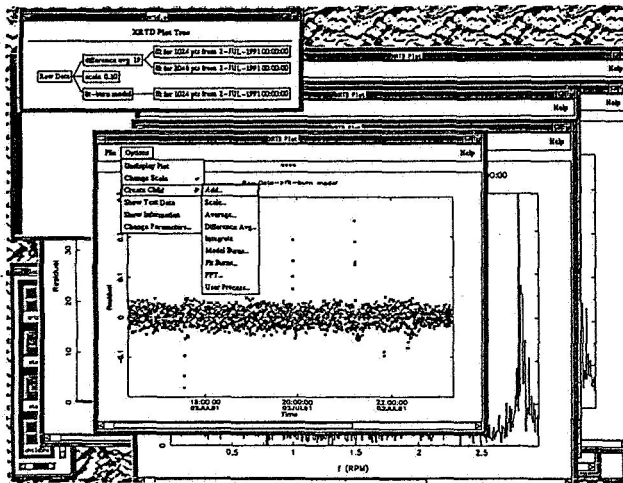


Figure 2: Xrtd windows with plot tree display

### 3. SYSTEM OPERATION

The entire *Xrtd* system is brought into operation when all four pieces of software are running. In practical application, the two pieces of software which transfer the raw tracking data run continuously. Only the latter two parts of the chain are generally started and stopped by the user. Additionally, the final part of the system, the *Xrtd* program itself, does not require real-time data, but can be run on old or simulated data. The *rtd* program is operated by giving it an input file which identifies the beginning time of data residuals to be calculated as well as the type (1 way Doppler, 2 way Doppler, 3 way Doppler, or range), and the desired tracking

station to be monitored. This then outputs the standard ASCII file which can be read by *Xrtd*.

#### 3.1 Xrtd description

As could be seen in Figure 2, *Xrtd* has many capabilities. A brief discussion of the major ones will be given here.

##### 3.1.1 File menu

The file menu has two entries, **Print Plot**, and **Exit**. **Print Plot** generates a PostScript image of the file which is then dumped to a PostScript compatible laserprinter. **Exit** exits the *Xrtd* program. A dialog box allows the user to abort the exit if desired.

##### 3.1.2 Options menu

The **Options** menu is the primary menu of the *Xrtd* program. It allows you to perform most of the capabilities of the *Xrtd* program and has six entries.

##### 3.1.2.1 Undisplay Plot

This command causes the current plot to cease to exist. This command is not accessible from the first plot.

##### 3.1.2.2 Change Scale

This menu item allows the user to rescale the plot without using the mouse. This is to allow the user to scale the plot larger than that which is currently displayed.

##### 3.1.2.2.1 Max Scale

This command changes the ordinate axis to include all data.

##### 3.1.2.2.2 MAD Scale

This scaling changes the ordinate axis by using an algorithm designed to result in the best looking scale. This scale will not include isolated points which are grossly offscale.

##### 3.1.2.2.3 Show All Data

This option changes both the ordinate and abscissa axes to include all data on scale.

#### 3.1.2.2.4 Manual Scale

This allows the user to input exact scale values to be used. Both the ordinate and the abscissa may be input.

#### 3.1.2.3 Create Child

The **Create Child** sub-menu is the route by which the user spawns new plots and analyzes the data.

##### 3.1.2.3.1 Add

This simply adds a constant bias to all residuals

##### 3.1.2.3.2 Scale

This input simply scales all residuals by an input scaling factor.

##### 3.1.2.3.3 Average

This allows the user to perform a forward looking moving average of the data. The number of points to average is a user input.

##### 3.1.2.3.4 Difference Average

This process calculates the difference between a given point and a centered average around the point. The number of points to use in the centered average is a user input. This process acts to filter out long period signatures in the data and to leave short period signatures present.

##### 3.1.2.3.5 Integrate

This process numerically integrates the residuals. This serves to convert Doppler residuals into the equivalent phase residual. This process often allows the user to see data characteristics that are too small to be discerned in the unintegrated data.

##### 3.1.2.3.6 Model Burns

This is a primary maneuver modeling tool. The user inputs the begin time, duration, initial value of residual at the beginning of the burn and final change in residual for any maneuvers. This capability allows the user to put in

maneuvers that have not yet occurred and assess very accurately in real-time the relative performance of the actual maneuver. If the maneuver has already occurred, the user can input all of the values by outlining the maneuver with the mouse. This is demonstrated in Figure 3.

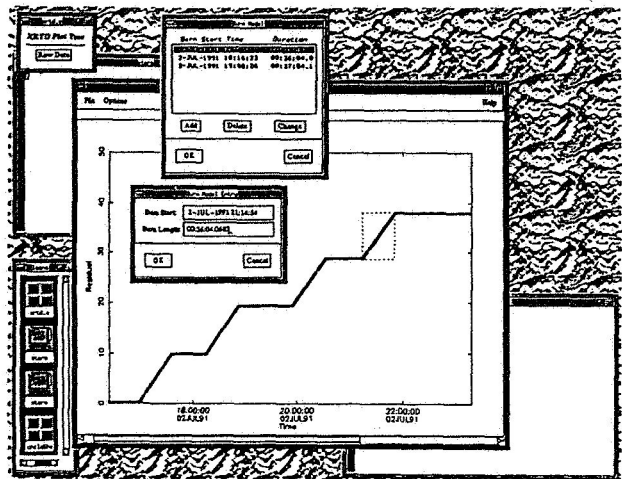


Figure 3: Use of mouse to input burn information

##### 3.1.2.3.7 Fit Burns

This tool is similar to **Model Burns**, but rather than inputting the expected value for the maneuver. The software attempts to fit polynomials through the data. One polynomial is fit from the beginning of the data arc to the beginning of the user defined maneuver span, one is fit through the maneuver, and one is fit from the end of the maneuver to the end of the data arc or to the next maneuver. As with the **Model Burns** menu item, the initial time and duration can be input using the mouse rather than the keyboard.

##### 3.1.2.3.8 FFT

This process will perform a Fast Fourier transform on the residuals. The beginning time for the transform and the number of points to be used are user inputs. The Fast Fourier Transform algorithm used requires the number of points used be a power of two. If not as many points exist after the beginning point as are requested, the plot will remain blank until enough points are available.

#### 3.1.2.3.9 User Process

This item allows the user to input the name of a user written, compiled, and linked program. The program allows the user to create any additional processes that are needed. The program reads in the timetag and residual from standard input and outputs the new timetag and residual to standard output.

#### 3.1.2.4 Show Text Data

The process shows a tabular listing of all the data displayed in the plot. The table is in three column format. The columns are point number, timetag (in Julian date), and residual.

#### 3.1.2.5 Show Information

This shows the results of the **Fit Burns** process. The output are polynomial coefficients and the time spans to which they apply.

#### 3.1.2.6 Change Parameters

This item allows the user to change the parameters of an already created window.

### 4. CONCLUSION

The *Xrtd* system has been utilized in its prototype form for two years. The system has performed wonderfully. Accurate determination of apparent maneuver performance has been achieved in only minutes compared to hours using previous systems. In addition, the Galileo Navigation Team has shown that the Fast Fourier Transform capability allows for rapid determination of spin rate and wobble amplitude. *Xrtd* has been used for the initial examination of the effectiveness of various attempts to free the Galileo High Gain Antenna. The system has regularly been used to determine the validity of data and to access in real-time the utility of various ground station configurations.

The system however still has some drawbacks. The data flow interface was generated to fit networks existing at the time of its inception. Improved networking ability may provide the opportunity to improve overall performance by changing the data flow path. Finally, like all systems which rely only on Doppler and range

data., all information obtained is only valid in the line of site between the receiving station and the spacecraft. To gain direct insight into the overall behavior, spacecraft telemetry data should be incorporated into the system. Currently, there is no capability for this. But it is hoped that future improvements to networking and data access will allow for the removal of these limitations.

### 5. ACKNOWLEDGEMENTS

The *Xrtd* system was originally developed as a Flight Project Support Office (FPSO) Advanced Technology Program proposal in 1990. Special acknowledgement must go to Earl Maize who led that original development as well as to those who contributed so much to the software used, Tim McElrath, Erik Slimko, and Peter Scott.

The research described in this paper was carried out by the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.

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